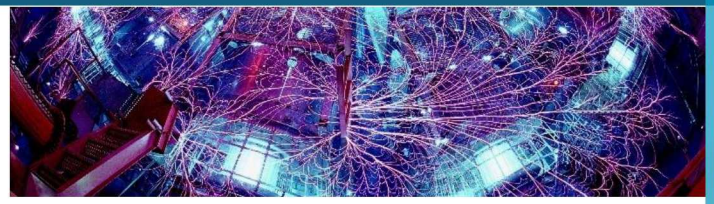
SAND2019-8405C

Sandia National Laboratories

Energy diverter switch geometries for use on pulsed power drivers enabling dynamic material physics experiments.





PRESENTED BY

Brian Stoltzfus, Landon Collier, Joseph Felix, and Cayetano Wagner

* Presented at the 2019 Pacific Symposium on Pulsed Power and Applications

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Outline

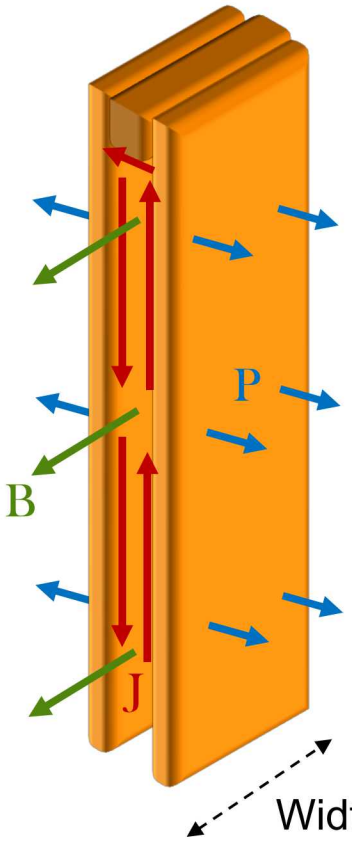
Part 1

- General Application: Using pulsed power to drive dynamic material physics experiments.
- Specific Machine at Sandia: Thor – 2.5 MA, 51 kJ stored, max pressure 50 GPa

Part 2

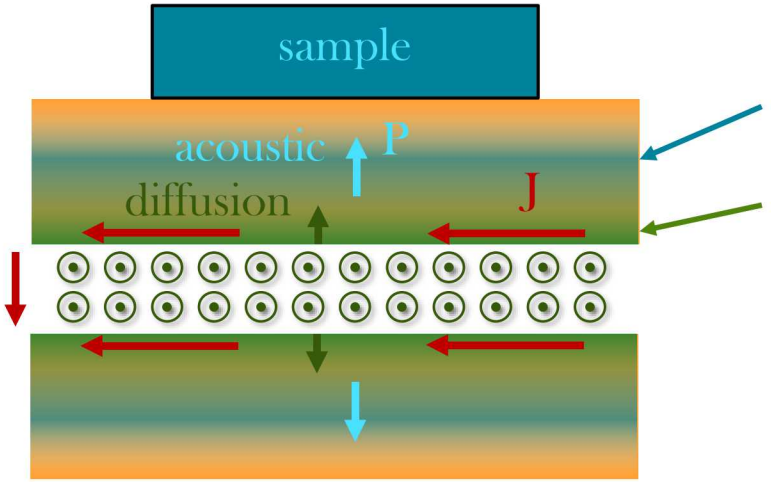
- General Tool: Energy diverter oil switch for configurations with significant reversal.
- Specific test results: four basic electrode geometries

Pulsed power drivers can be used to generate acoustic pulses for material physics experiments.



$$J \times B = Force$$

$$P = \frac{1}{2}\mu\left(\frac{I}{w}\right)^2$$

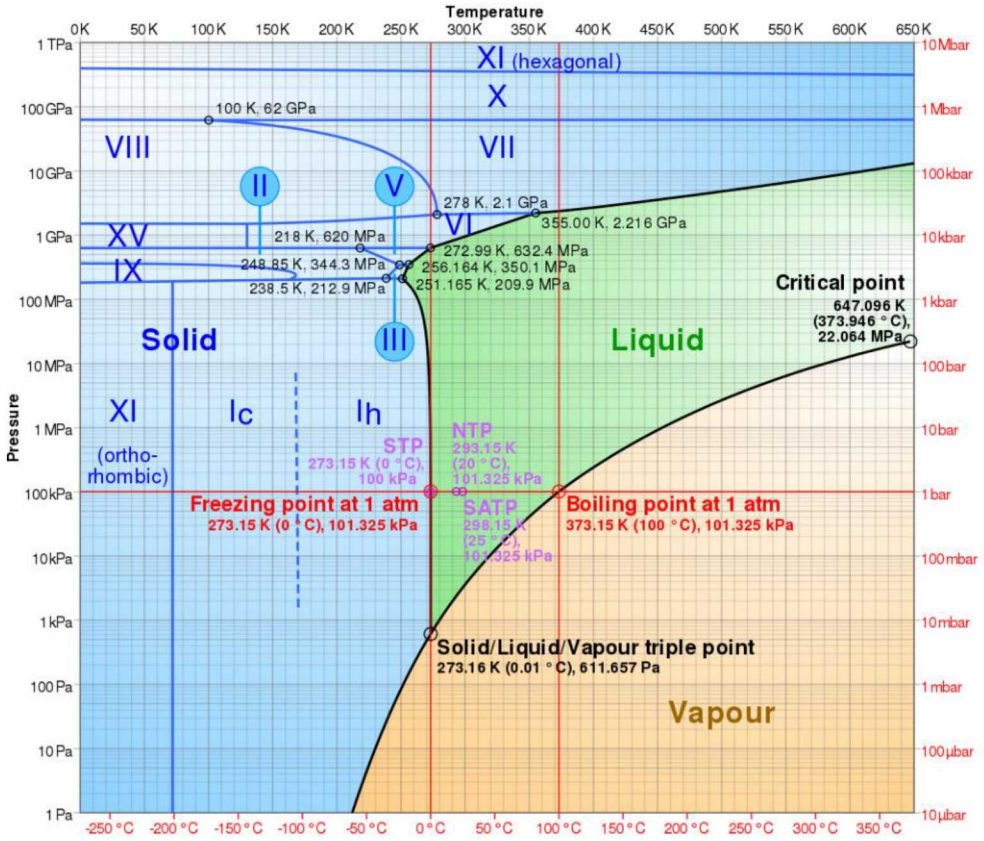


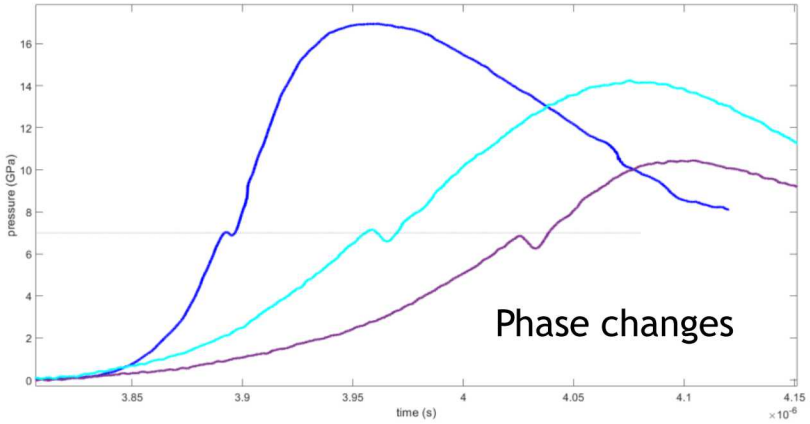
Acoustic wave velocity (sound speed, 2-6 km/s)

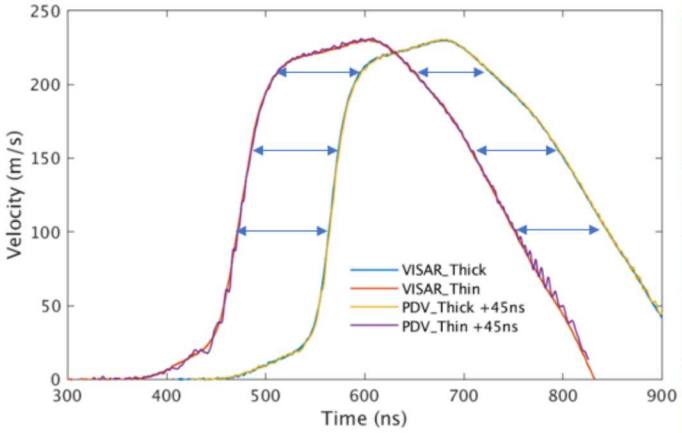
Magnetic diffusion velocity (<2 km/s)

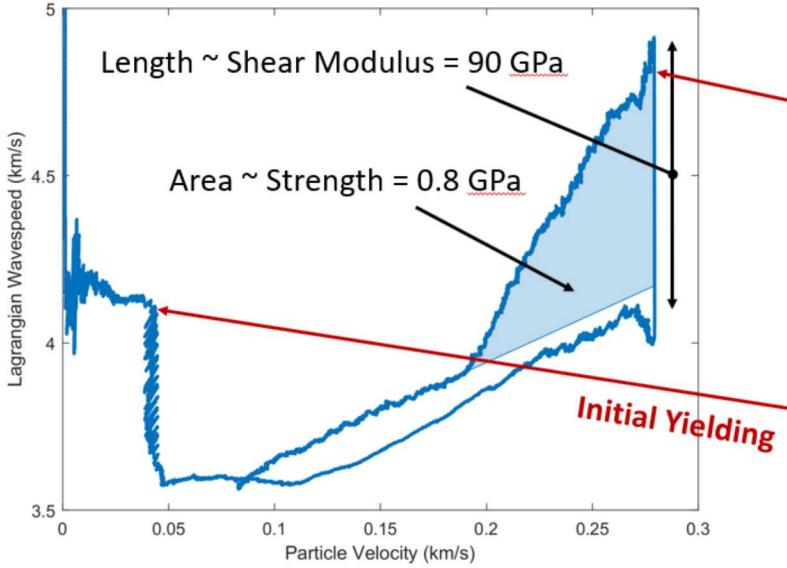
Currents flowing on a flat plate generate 1-D pressure waves if the gap between the plates is small relative to the length and width of the plates.

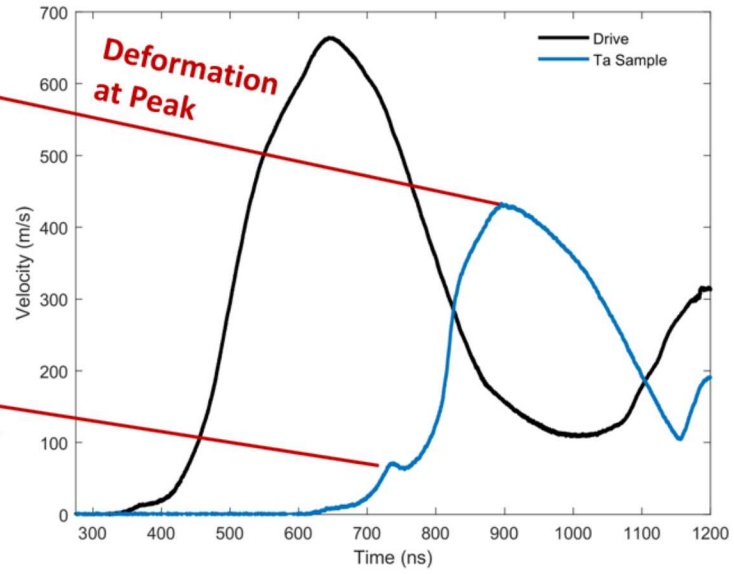
These acoustic pulses can be used to measure sound speed, material strength, or Equation Of State (EOS) type material properties under dynamic conditions.





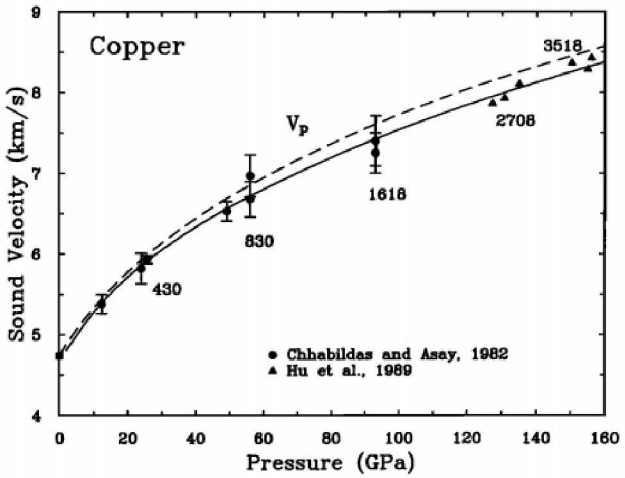


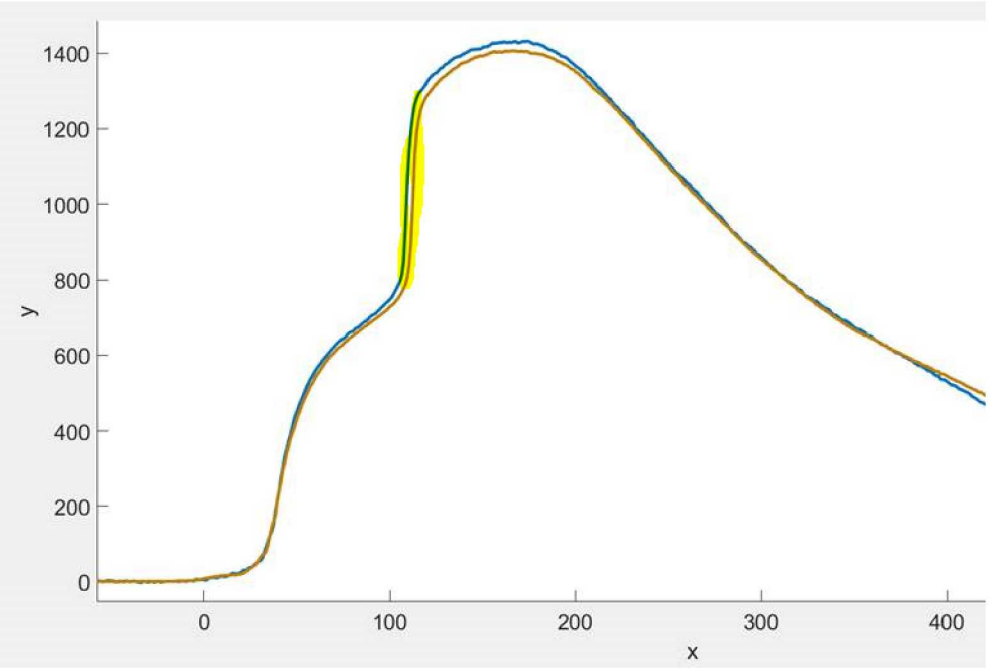


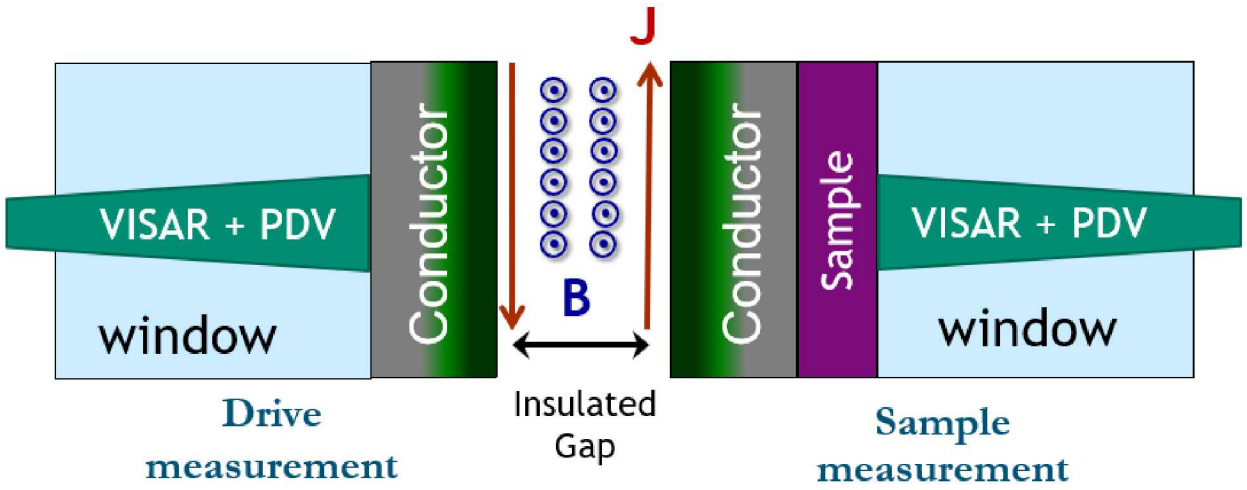


Tailoring the current pulse allows you to tailor the acoustic pulse.

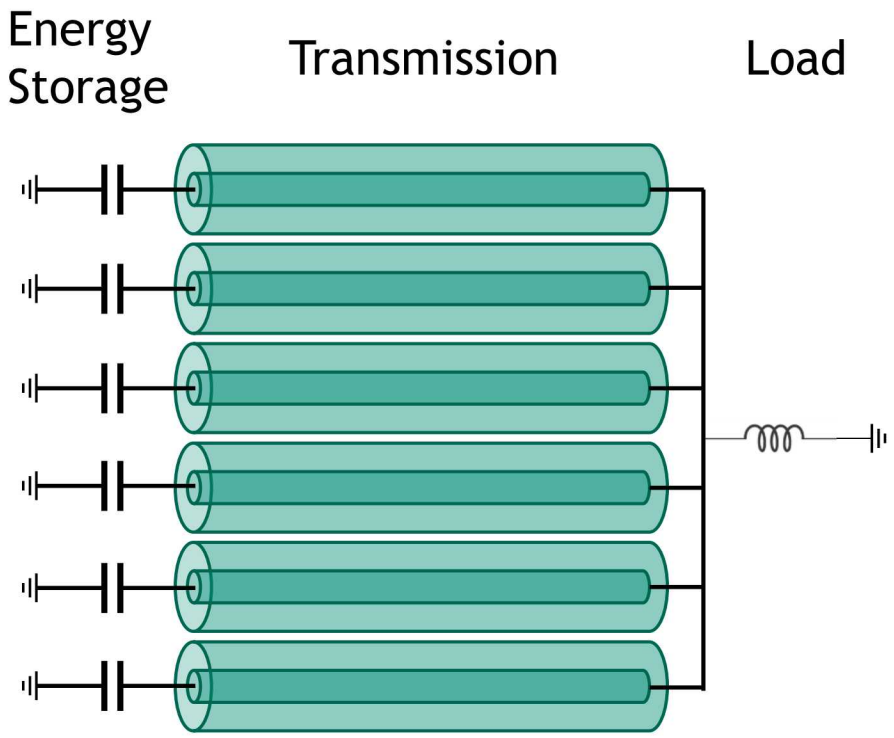
- Tailoring allows you to avoid shocking the material and to adjust the loading rate.
- Shock waves can be hard to avoid because the wave speed increases with pressure.
- Examples where tailoring the pulse is useful
  - Kinetics of phase transitions
  - Observe strain rate effects
  - Ramp and hold pressure

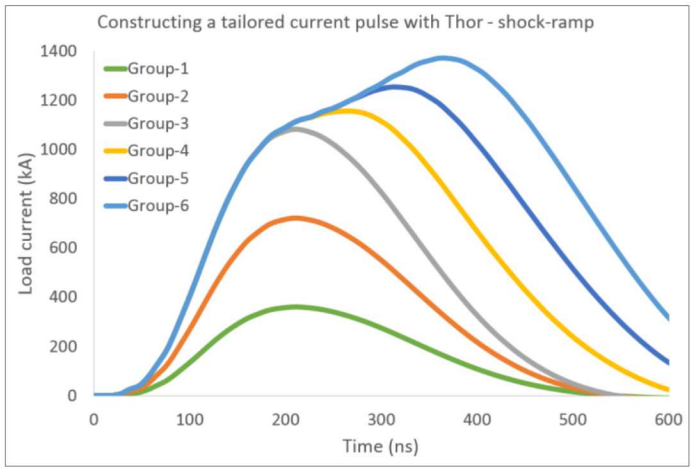


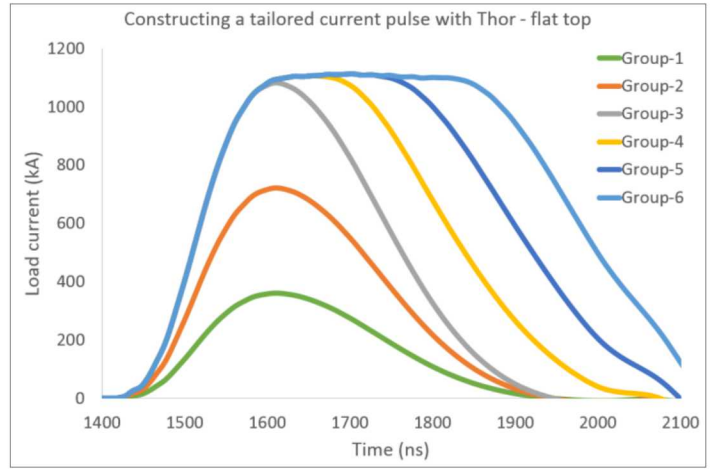


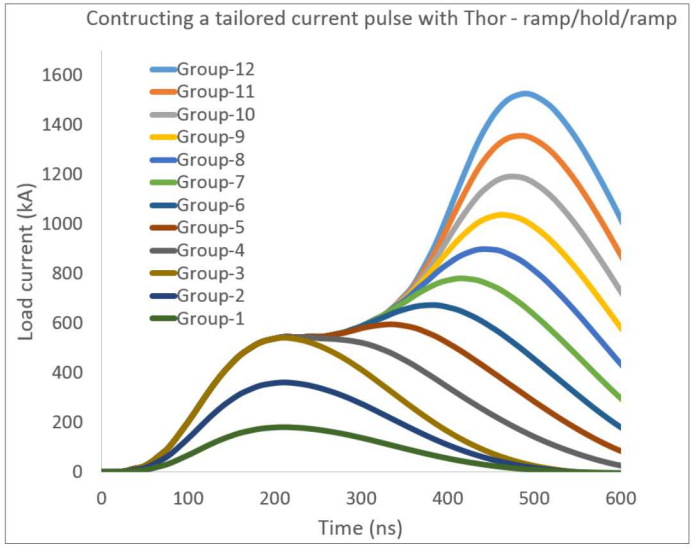


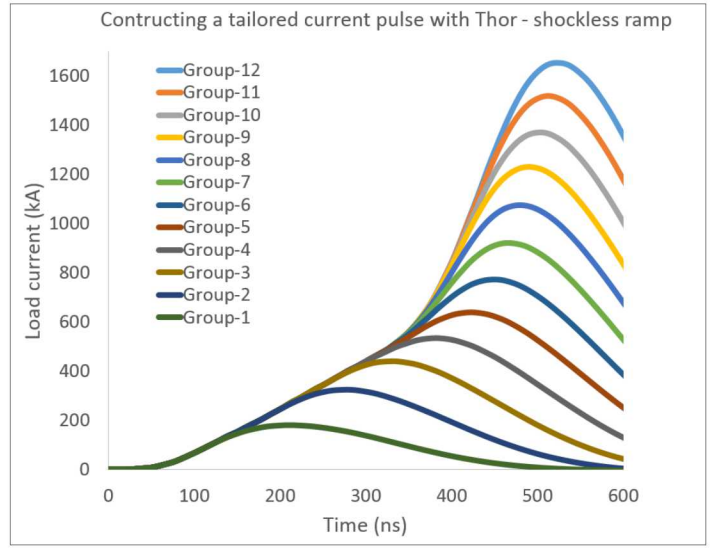
Transit time isolation between energy store and load allows for easy pulse shaping and adjustment.



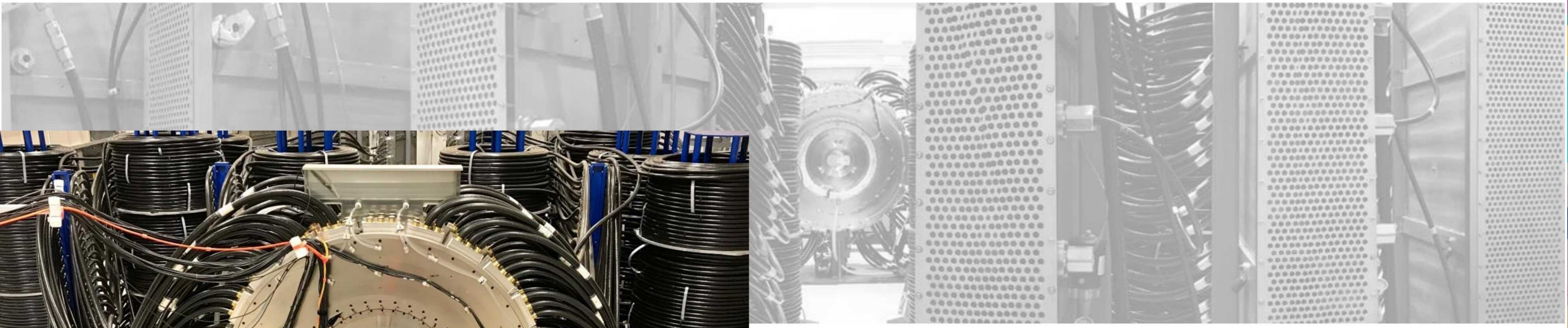


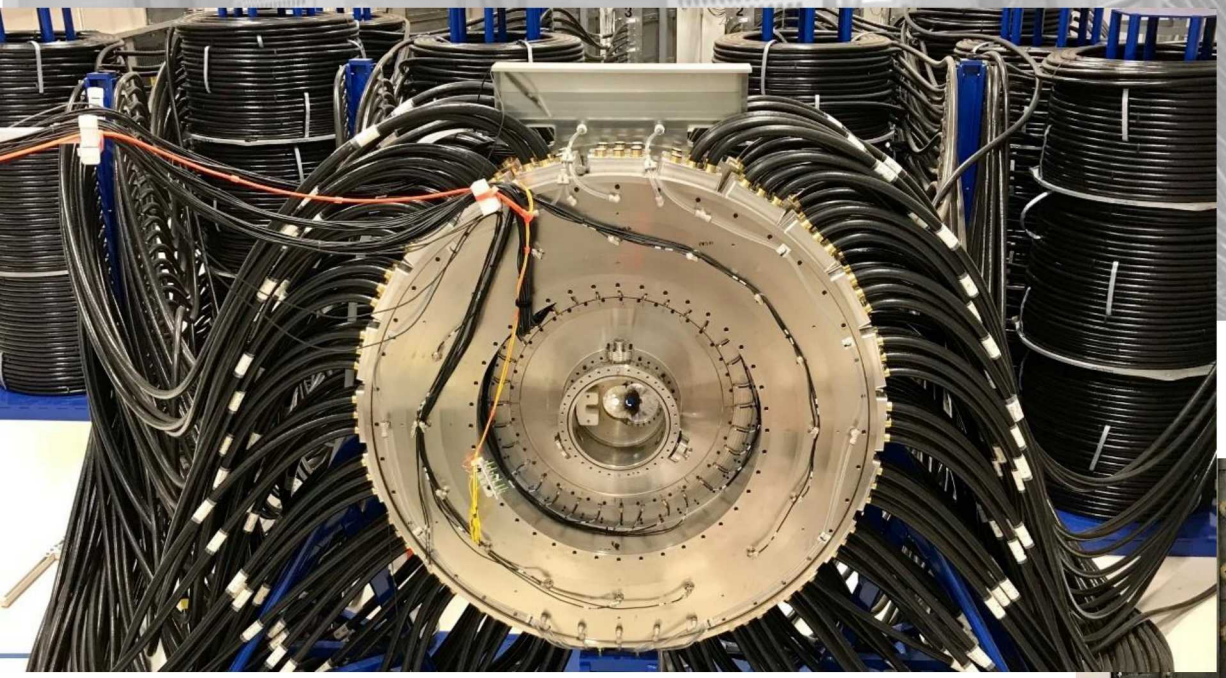


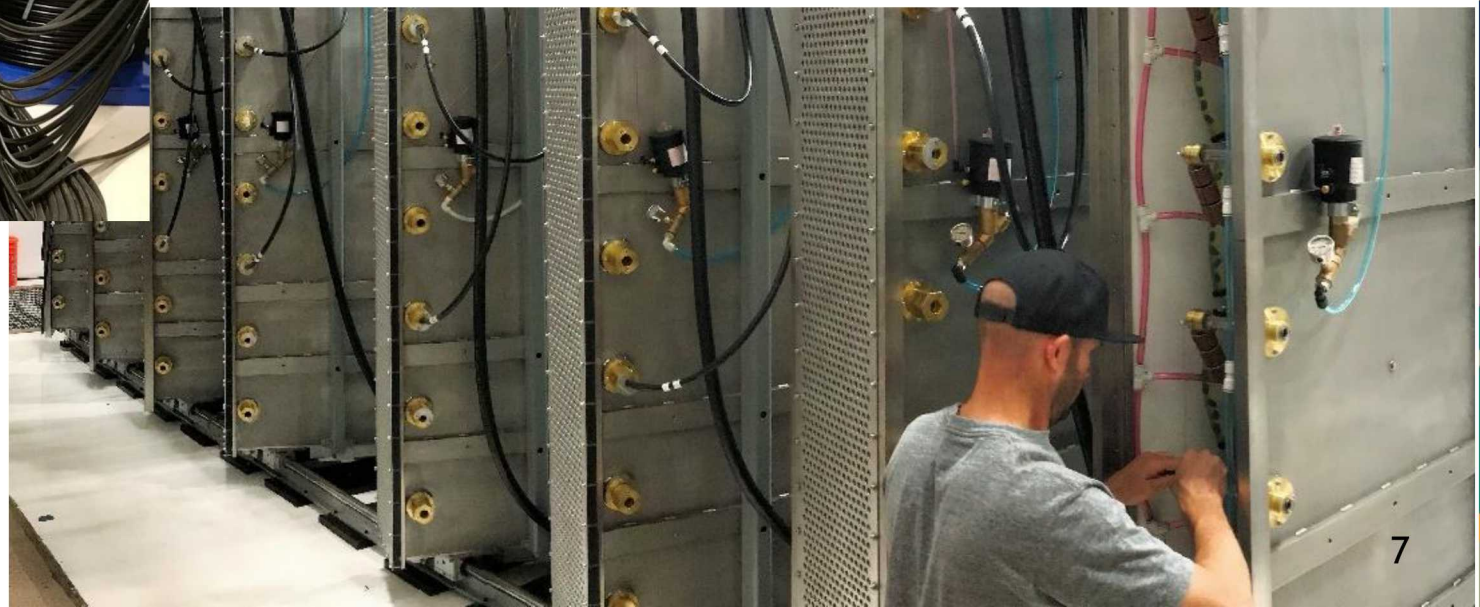




Thor is a new pulsed power driver at Sandia for dynamic material physics experiments.



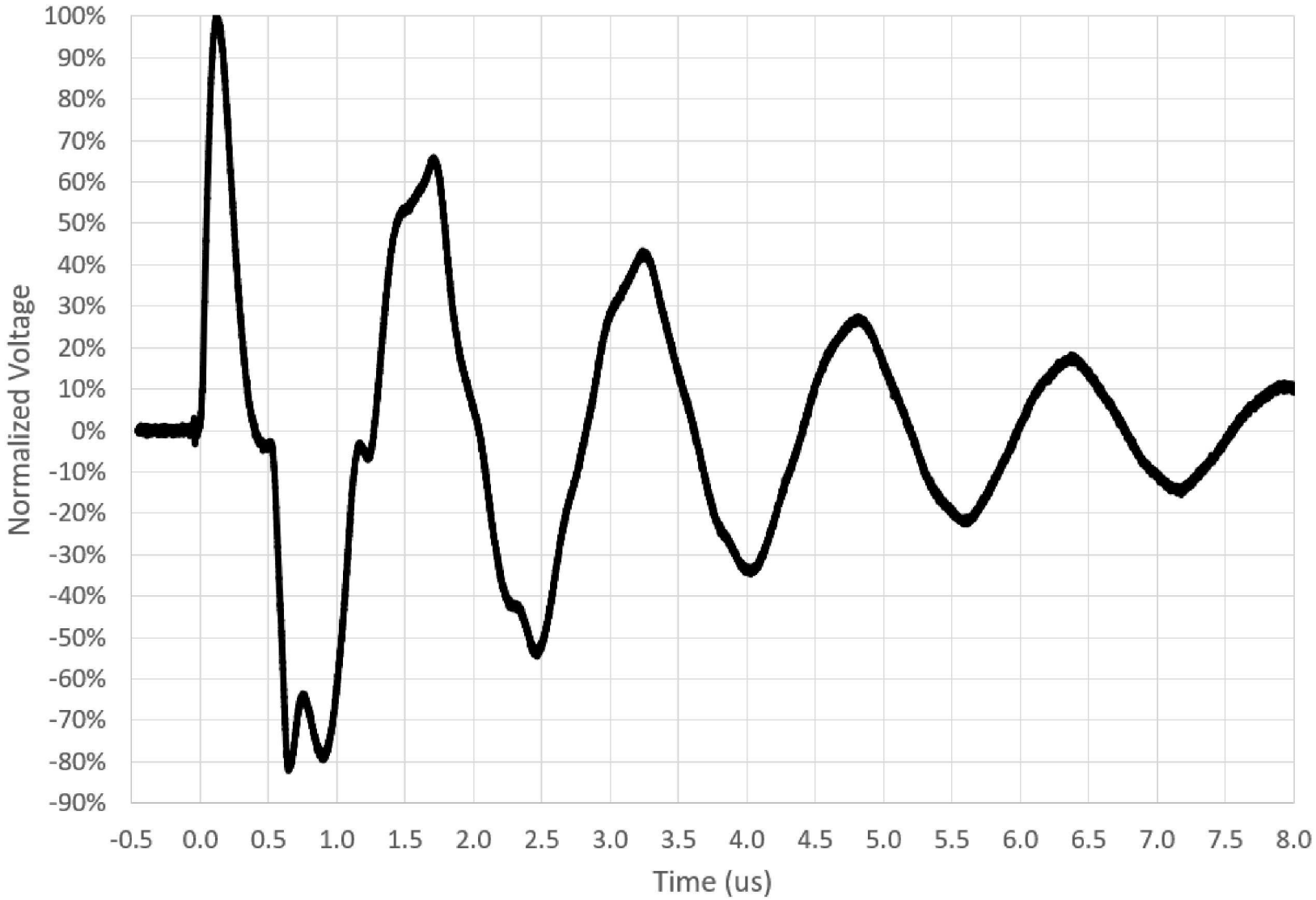




- Stores 51 kJ of electrical energy
- Outputs ~2.5 MA into a standard load
- Pulse shaping over a 500 ns window
- 20-30 GPa pressures with ~50 GPa peak
- ~$1 k per shot and 1 shot per day
- Flexible shot schedule and load config

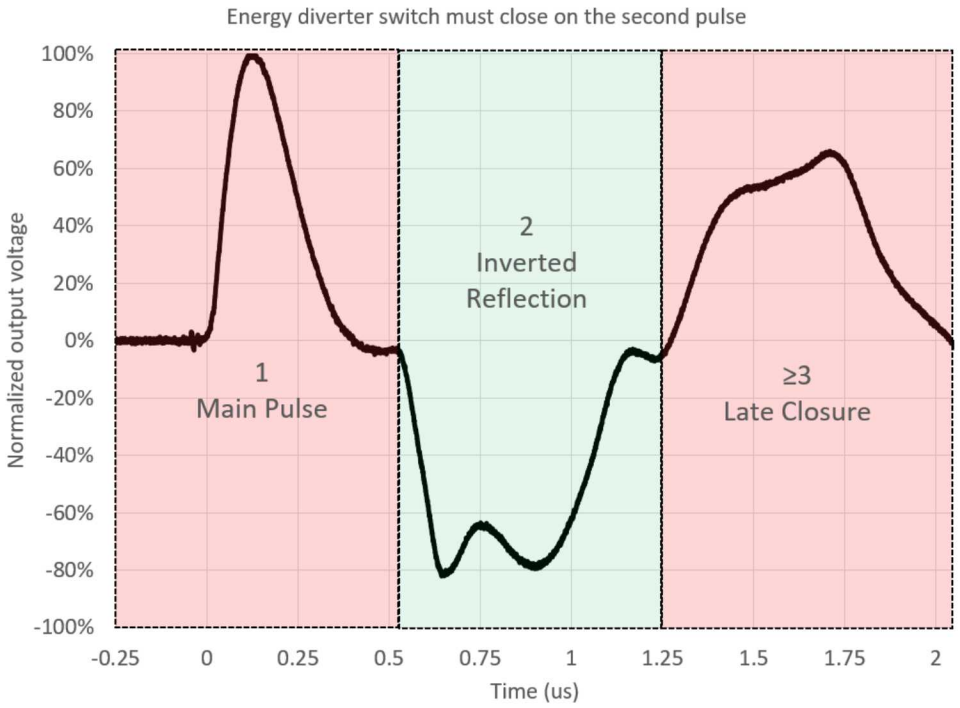
Part 2: Most experimental loads are lower impedance than the driver and result in significant voltage reversal in the driver.

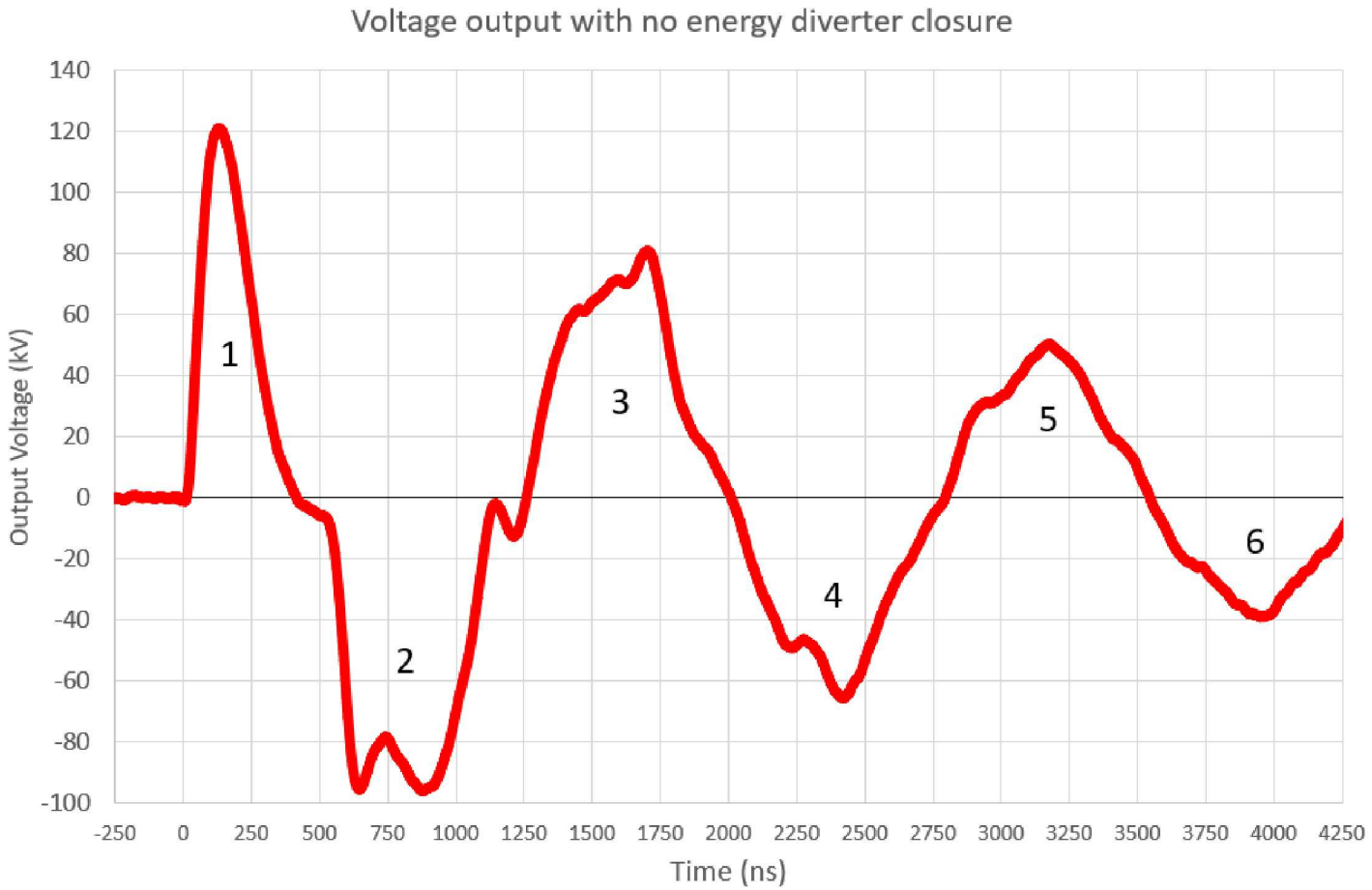
$$Z_{driver} \geq \frac{L_{load}}{\tau_{rise}}$$

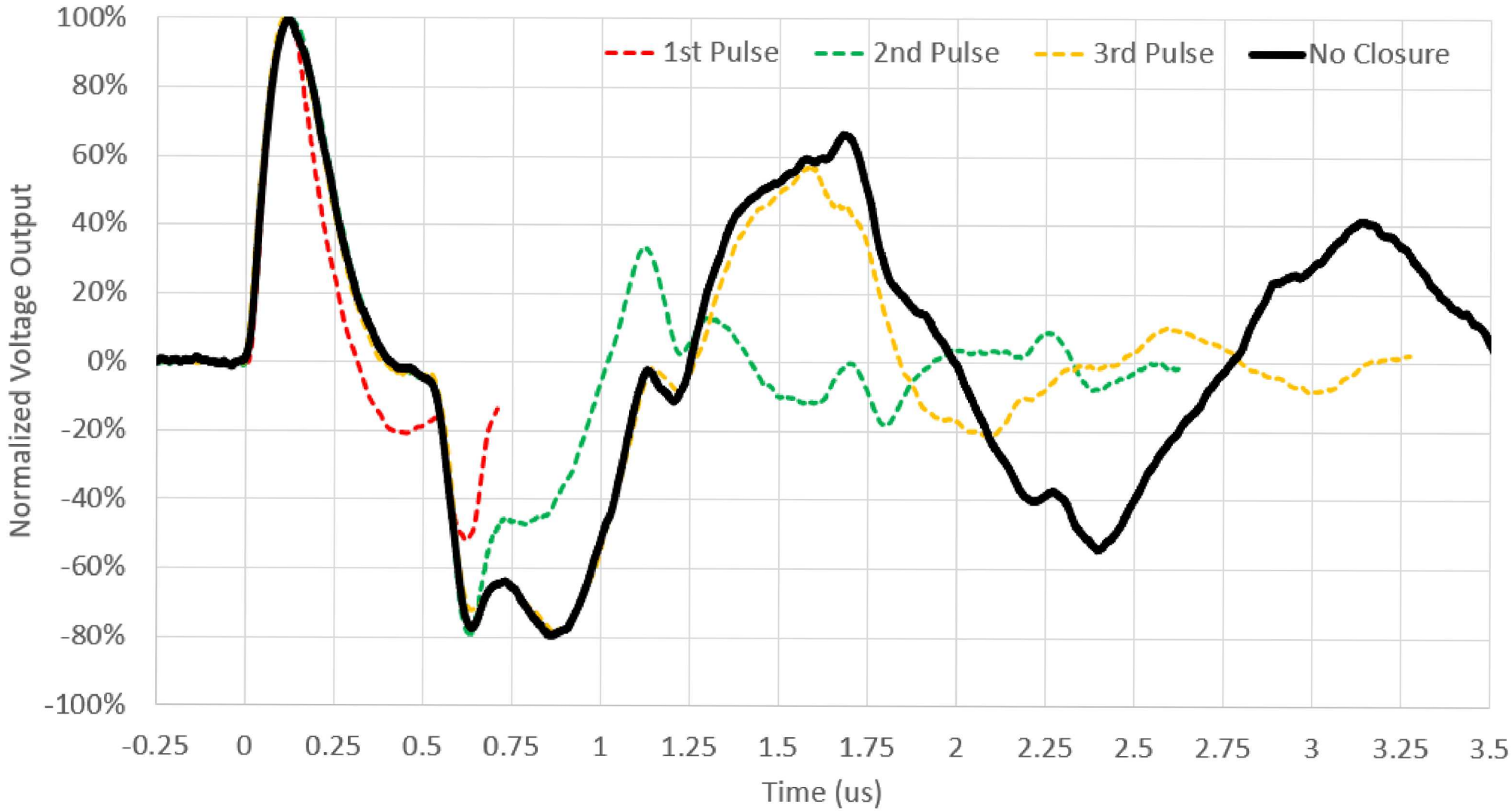


To protect the energy storage units from the stress of high reversal, energy diverters can be used effectively.

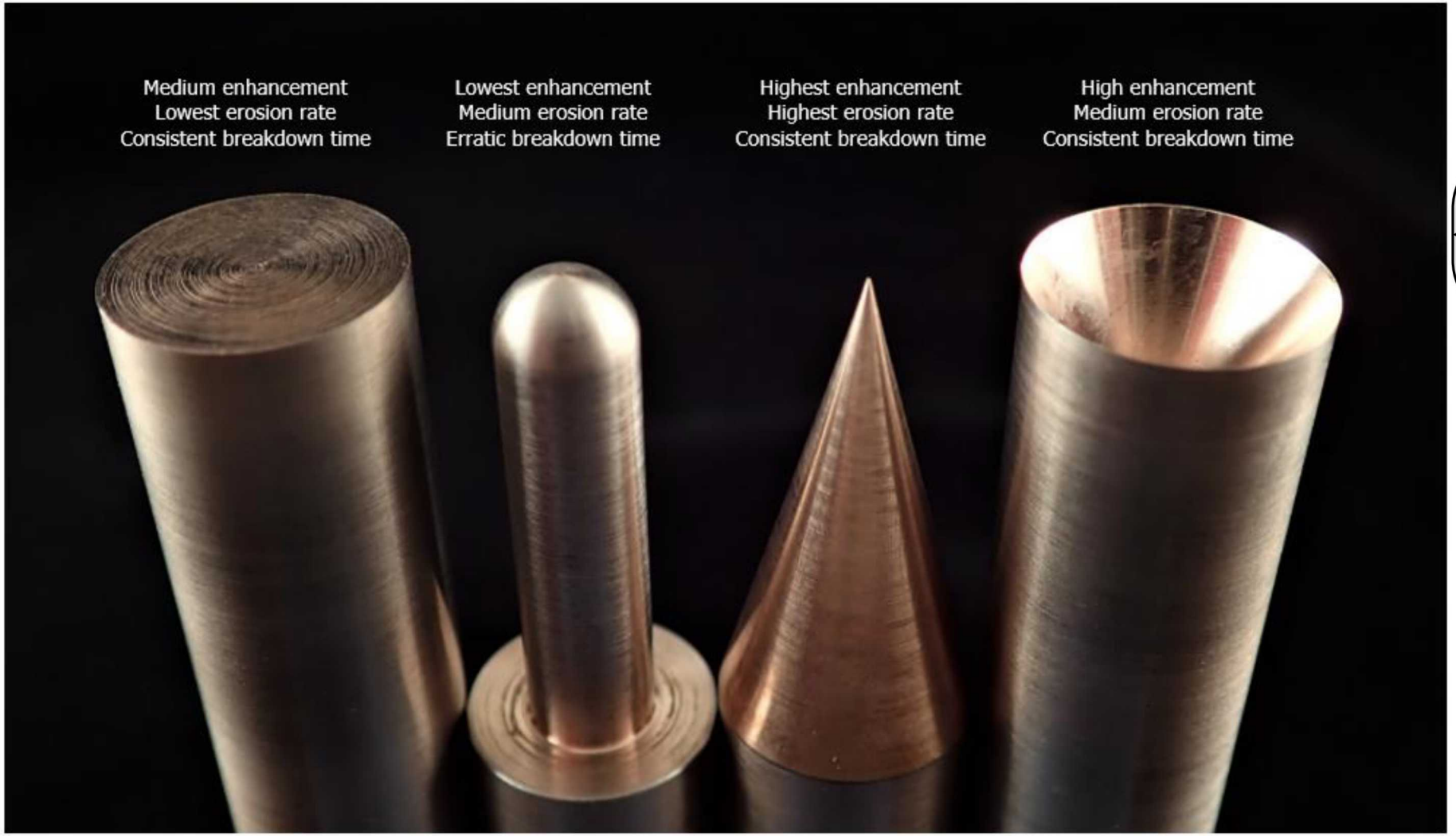
- The transit time helps isolate the reflected pulse from the initial pulse.
- The reflected pulse is always reverse polarity, so the diverter can exploit a polarity effect.

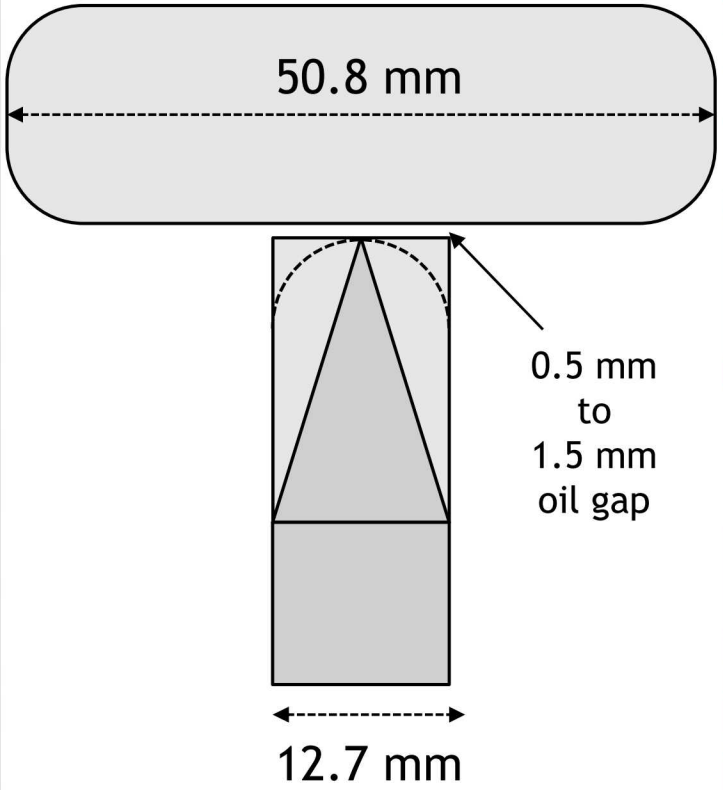


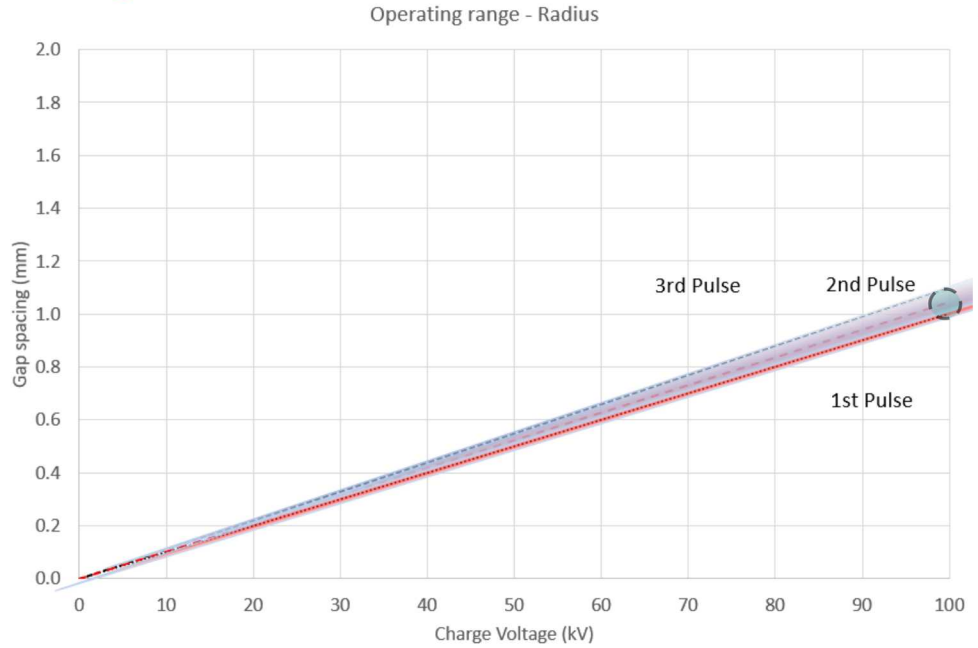


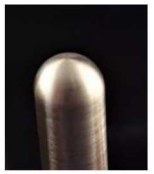

1st Pulse
2nd Pulse
3rd Pulse
No Closure
Normalized Voltage Output
100%
80%
60%
40%
20%
0%
-20%
-40%
-60%
-80%
-100%
-0.25
0
0.25
0.5
0.75
1
1.25
1.5
1.75
2
2.25
2.5
2.75
3
3.25
3.5
Time (us)

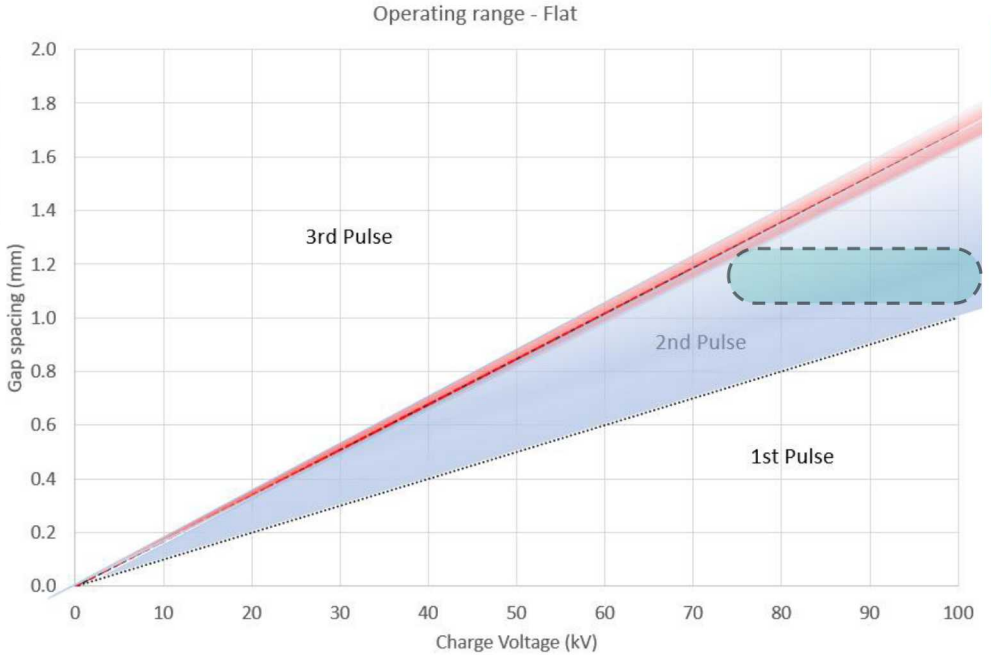
We evaluated the performance of four different electrode geometries in both polarities.

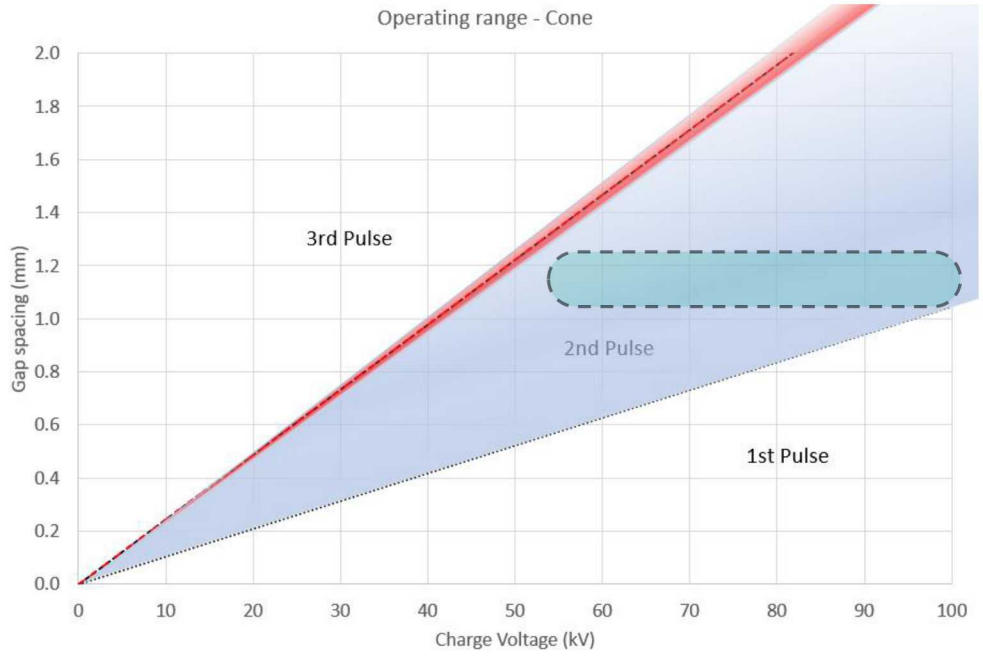


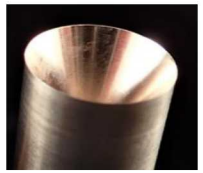


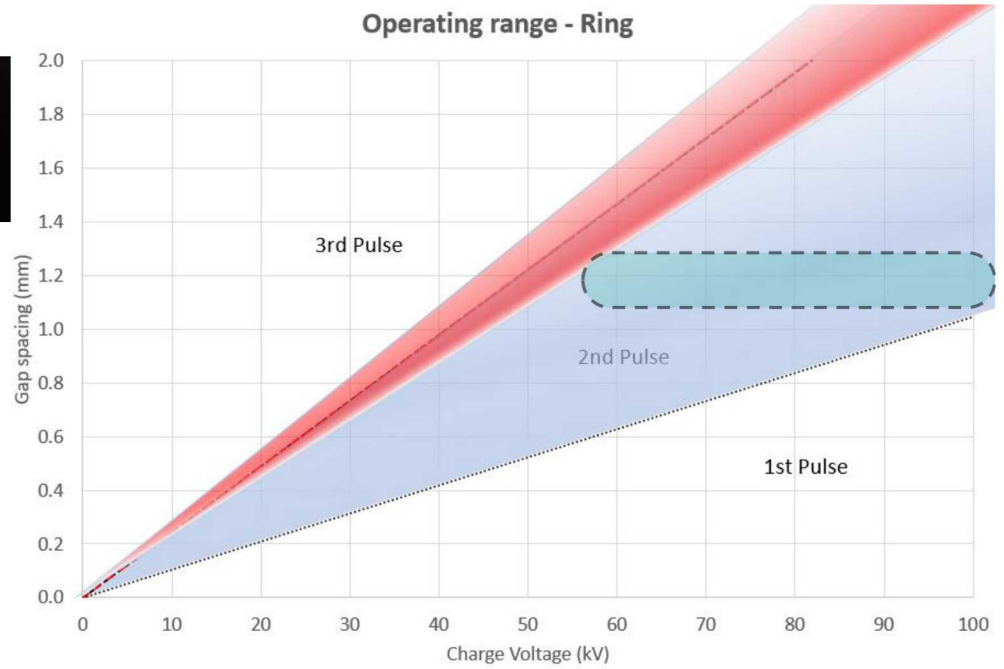

Operating range - Radius
Gap spacing (mm)
Charge Voltage (kV)
3rd Pulse
2nd Pulse
1st Pulse



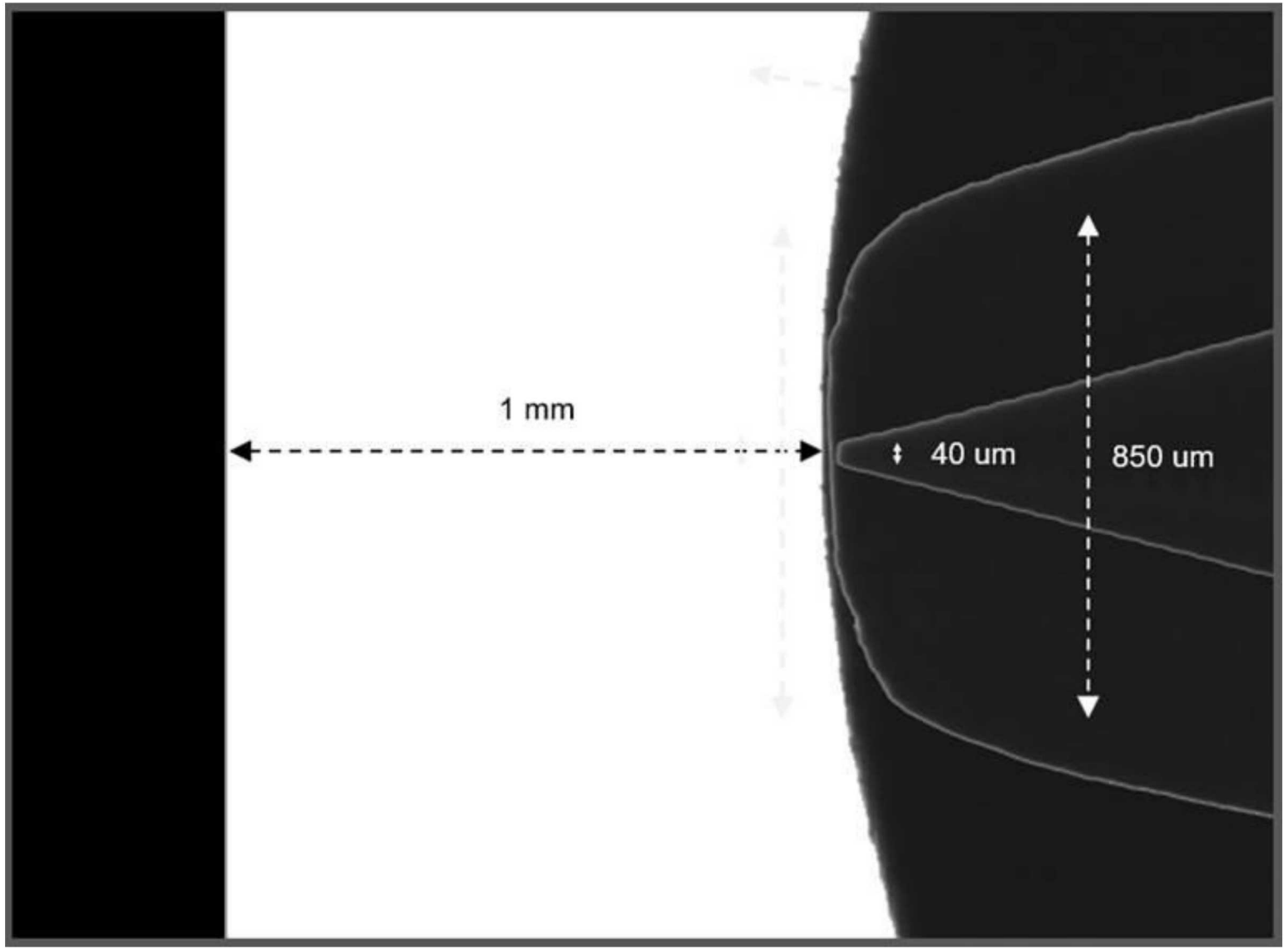

Operating range - Flat
Gap spacing (mm)
Charge Voltage (kV)
3rd Pulse
2nd Pulse
1st Pulse


Operating range - Cone
Gap spacing (mm)
Charge Voltage (kV)
3rd Pulse
2nd Pulse
1st Pulse




Operating range - Ring
Gap spacing (mm)
Charge Voltage (kV)
3rd Pulse
2nd Pulse
1st Pulse

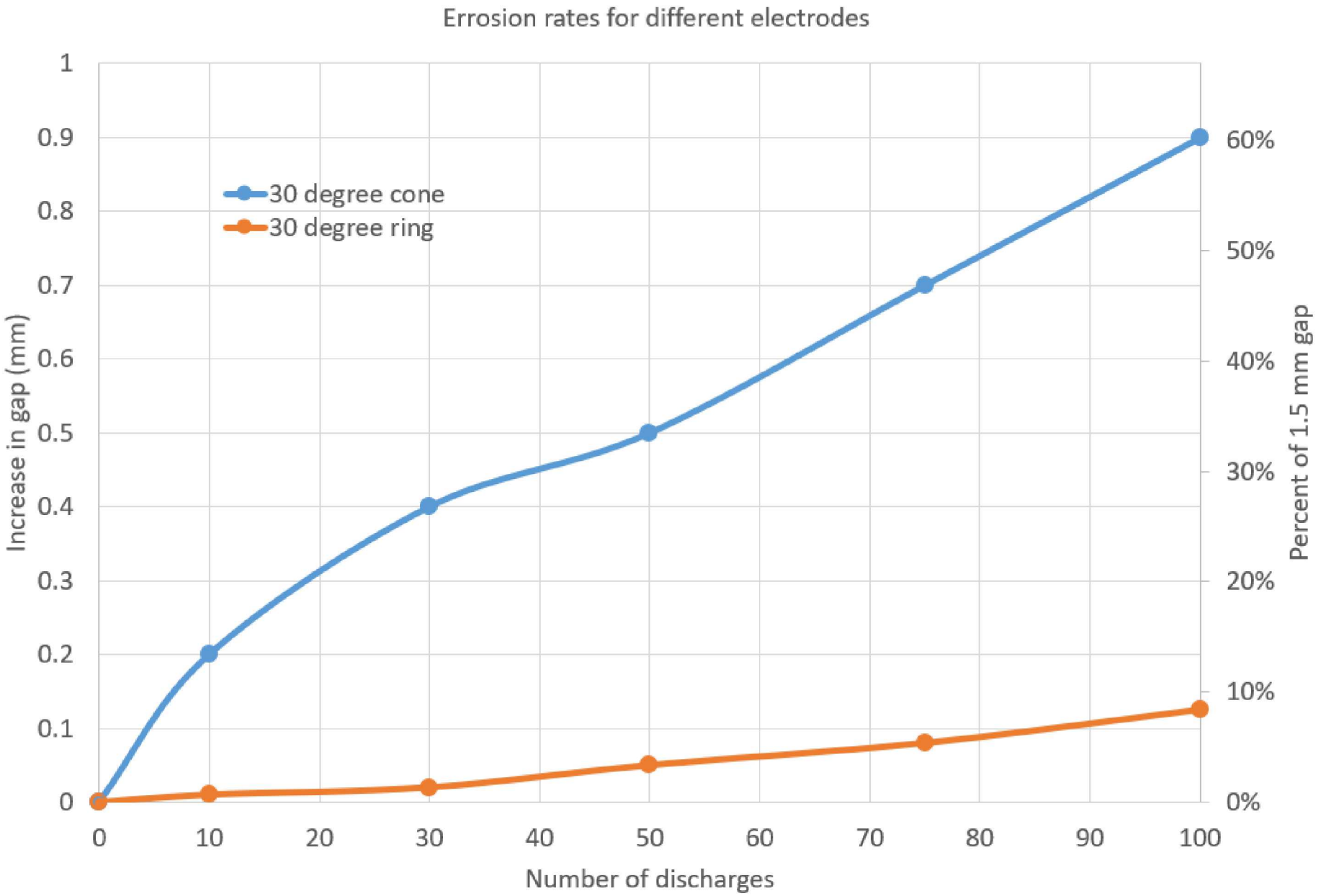
Erosion rates for “cone” electrode.



Erosion after ~150 discharges

- Peak Current = ~40 kA
- Energy stored = ~800 J
- Charge transfer = ~10 mC

Electrode erosion rate



Conclusion

Part 1

- Material physics is a solid application for pulsed power.
- The ability to shape the acoustic wave with the current pulse is key.
- Transit time isolated pulses are a convenient way to accomplish this goal.

Part 2

- Energy diverters are a useful too for dissipating late time energy, especially when the energy storage is transit time isolated from the load.
- Applications with low impedance loads (high reversal) can exploit the polarity effect in liquids.
- The “ring” electrode geometry is a good balance between closure performance and erosion rate.

Backup slides

Test configuration.

Oil quality – humidity and particle

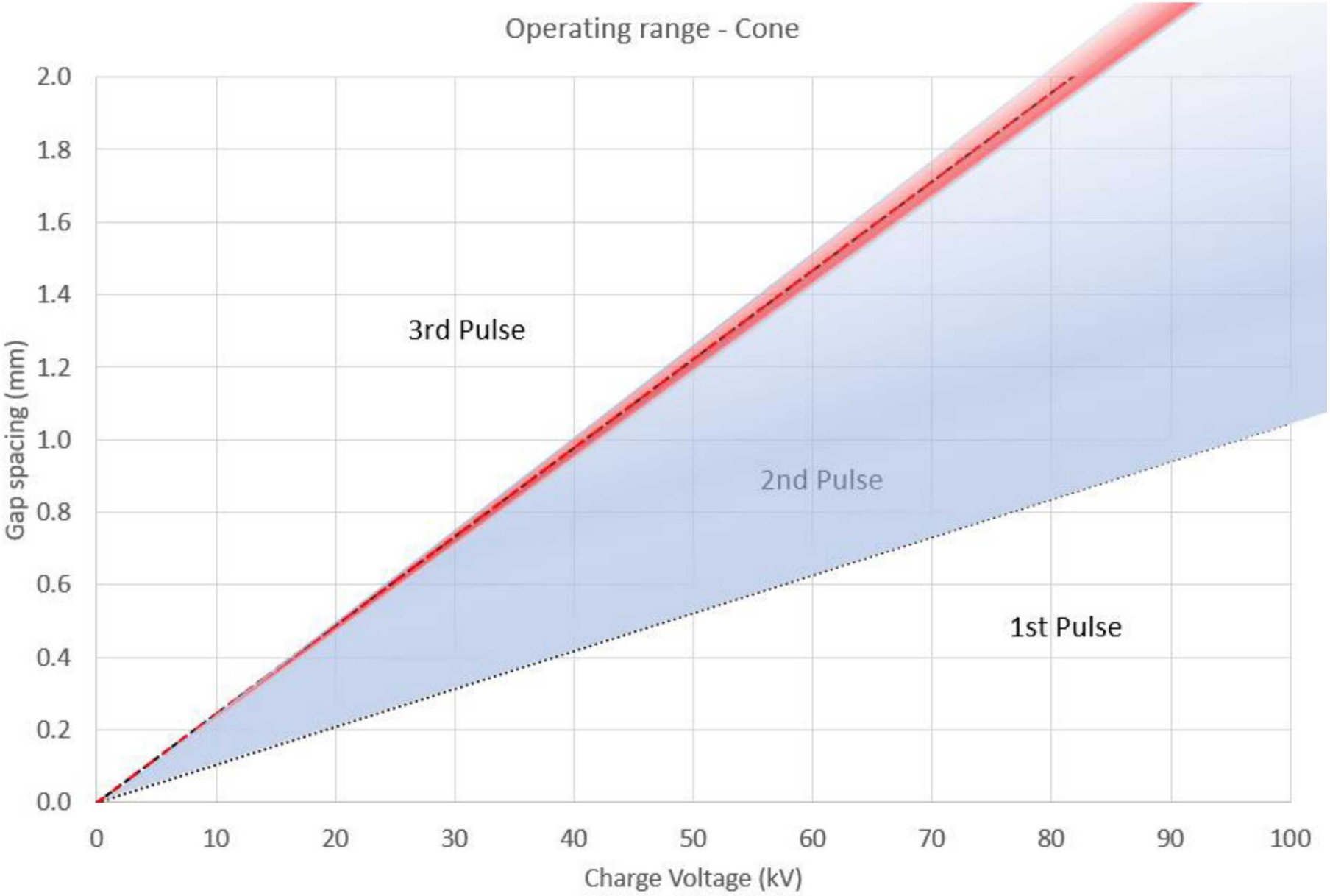
- ~10-20% RH

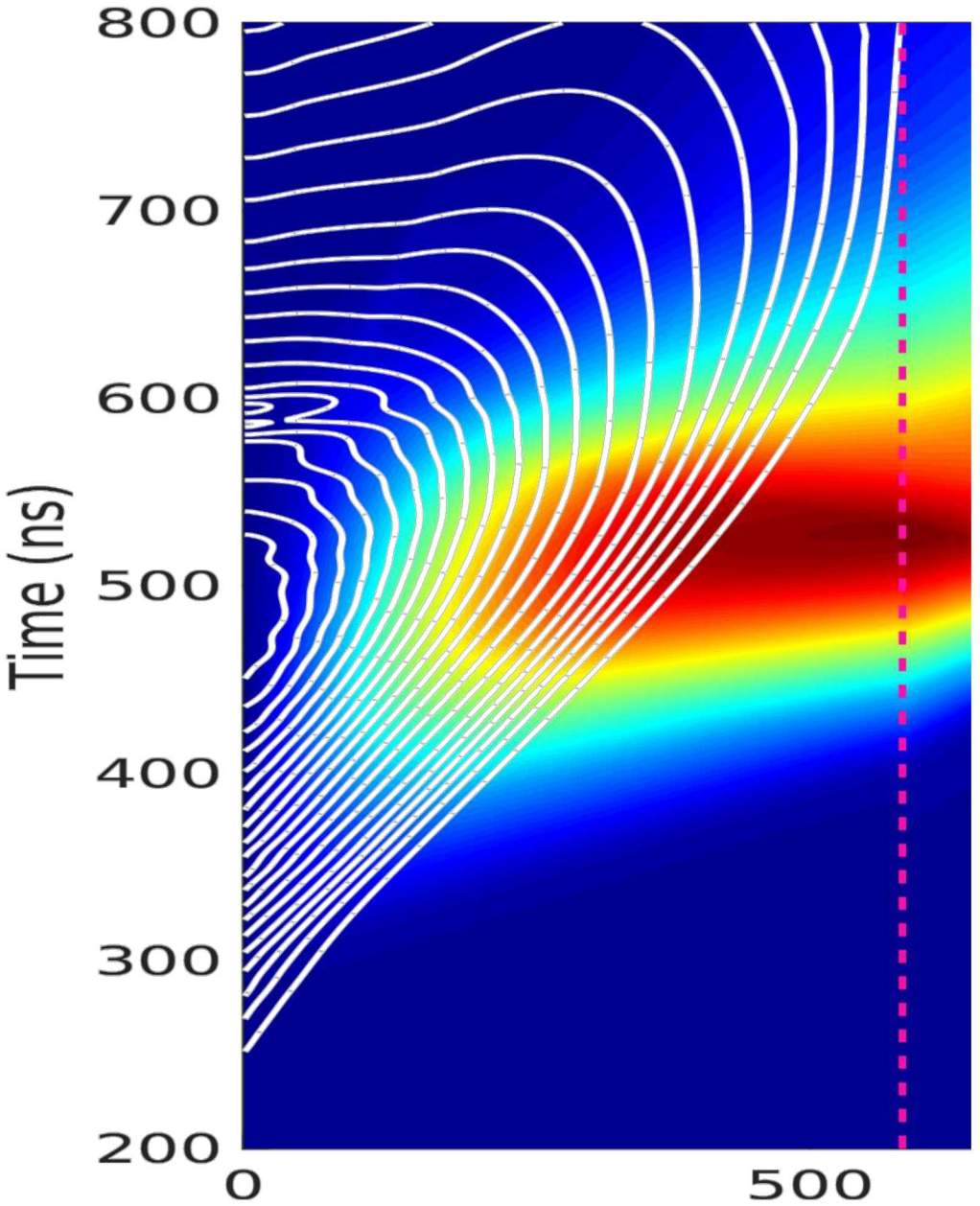
Gap range – 0.5 to 2.0 mm
Pulse rate – one shot a min
Oil flow across gap to clear bubbles at 1 GMP

Results.

Config	Lower range (kV)	Upper range (kV)	Operational range (kV)	Notes
Point – NEG 10 div	35-50	95	50-60	>20 shots? (new tip for lower)
Point – POS 10 div	45-55	45-55	0-5	>20 shots?
Ring – NEG – 10 div	40	90	50	(~10 shots) could refine
Ring – POS – 10 div	35	45	0-5	(~10 shots) could refine
Flat – NEG – 9 div	67	97	30	
Flat – NEG – 10 div	75	100	25	
Flat – NEG – 11 div	75	>100	>25	
Flat – POS – 10 div	?	?	0-5?	(need to do positive run)
Radius – NEG – 8 div	75	75	0	(~10 shots) – no op range
Radius – NEG – 10 div	100	100	0	(~30 shots) – no op range
Radius – POS – 8 div	65	65	0	(~10 shots) – no op range

Polarity effect




800
700
600
500
400
300
200
Time (ns)
0
500

Tailoring the current pulse allows you to tailor the acoustic pulse.

- Tailoring allows you to avoid shocking the material and to adjust the loading rate.
- Shock waves can be hard to avoid because the wave speed increases with pressure.
- Examples where tailoring the pulse is useful
  - Kinetics of phase transitions
  - Observe strain rate effects
  - Ramp and hold pressure